

JOINT ROUTING PROTOCOL AND IMAGE COMPRESSION ALGORITHM
FOR PROLONGING NODE LIFETIME IN WIRELESS SENSOR NETWORK

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A thesis submitted in
fulfillment of the requirement for the award of the
Degree of Doctor of Philosophy of Electrical Engineering

Faculty of Electrical and Electronic Engineering
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OCTOBER 2018

To my family and friends



ACKNOWLEDGEMENT

A humble gratitude to Almighty ALLAH for blessing me with the opportunity and strengthening to complete the work.

I would like to express my heartiest thanks to my supervisor Assoc. Prof. Dr. Jiwa Abdullah whose encouragement, guidance and support enabled me to carry out this research work.

Most importantly I would like to thank my parents, friends and family for supporting me spiritually throughout this work.



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ABSTRACT

Wireless sensor network (WSN) are among the emerging modern technologies, with a vast range of application in different areas. However, the current WSNs technology faces a key challenge in terms of node lifetime and network connectivity due to limited power resource of the node. The conventional data routing protocols do not consider the power available at the node on the path from source to sink, thus they result in the exhaustion and eventual death of nodes surrounding the sink node, thus generating routing holes reducing the network throughput. In order to address the issue in this research presents a novel protocol based on equal power consumption at all network nodes. The consume power fairly (CPF) protocol achieves a high power efficiency by distributing power consumption equal on all the network nodes. The protocol compares the power available on all the paths from source to sink and then selects the path with highest power. Additionally in order to reduce the transmitted data size, a lossy image compression technique based on adaptive Haar wavelet transform has been implemented. The simulation designs based on MATLAB consists of 100 randomly distributed nodes over an area of 100 m^2 , with 30 Kbits and 40 Kbits of packet sizes. The comparison between the proposed CPF protocol and the energy aware protocol has been carried out on the basis of number of iterations and the dead nodes in the network. Thorough simulations have been carried out based on different number of network iterations to validate the potential of the proposed solution. Moreover the implemenetation of multiscale retinex technique results in image enhancement and improved classification. An implementation of the CPF protocol and image compression technique on a 100 node network with 500 iterations, results in the death of 13 nodes as compard to 38 dead nodes with energy aware protocol for the same network. Thus the performance comparision of CPF and energy aware protocol demonstrates an improvement of 81.19% for the energy consumption of the network. Thus the proposed algorithm prolongs the network under consideration by 57 – 62% as compared to networks with conventional routing protocols.

ABSTRAK

Rangkaian sensor tanpa wayar (WSN) adalah antara teknologi moden yang baru muncul, dengan julat aplikasi yang luas mencakupi berbagai bidang. Walaubagaimanapun, teknologi WSN semasa menghadapi cabaran utama dari segi jangka hayat nod dan sambungan rangkaian disebabkan sumber kuasa terhad bagi sesuatu nod. Protokol penghalaan data lazim tidak mengambil kira kuasa yang berada di dalam nod di atas laluan dari punca ke sink, oleh itu ia menyebabkan kehilangan kuasa dan akhirnya berlaku nod mati di sekeliling nod sink, yang mana akhirnya menghasilkan lubang penghalaan dan mengurangkan hasil pemprosesan rangkaian. Untuk menangani masalah dalam penyelidikan ini, suatu protokol yang baharu berasaskan penggunaan kuasa yang seimbang bagi semua nod rangkaian. Protokol penggunaan kuasa secara adil (CPF) menghasilkan kecekapan kuasa yang tinggi dengan mengagihkan penggunaan kuasa yang sama pada semua nod rangkaian. Protokol ini membandingkan kuasa yang terdapat pada semua laluan dari sumber ke sink dan kemudian memilih laluan yang mempunyai kuasa tertinggi. Tambahan lagi, bagi mengurangkan saiz data yang dihantar teknik pemampatan imej berasaskan transformasi wavelet Haar adaptif diperkenalkan. Rekabentuk penyelakuan adalah berdasarkan kepada perisian MATLAB mengandungi 100 nod teragih secara rawak dalam kawasan 100 m^2 , dengan saiz paket 30 kbit dan 40 kbit. Perbandingan di antara protokol CPF yang dicadangkan dan protokol berasaskan tenaga yang berada di pasaran, telah dilaksanakan dengan kadar iterasi dan bilangan nod yang mati dalam rangkaian. Penyelakuan menyeluruh yang dilakukan adalah berdasarkan bilangan iterasi untuk memastikan penyelesaian yang dicadangkan adalah tepat. Pelaksanaan menggunakan teknik pelbagai skala retineks menghasilkan imej yang baik dan meningkatkan keupayaan pengelasan. Pelaksanaan protokol CPF dan teknik pemampatan imej ke atas 100 node dan 500 iterasi, membawa kematian nod hanya 13 berbanding dengan 38 nod mati menggunakan protokol sedar tenaga. Oleh itu perbandingan prestasi bagi protokol sedar tenaga dan CPF bersama dengan pemampatan imej menunjukkan peningkatan sebanyak 81.19 penggunaan tenaga yang

lebih efisien. Oleh itu algoritma yang dicadangkan memanjangkan hayat rangkaian yang dipertimbangkan kepada 57 - 62% berbanding dengan rangkaian dengan protokol penghalaan lazim.



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LIST OF ABBREVIATIONS

<i>ACK</i>	-	Acknowledgment
<i>ACT</i>	-	Adaptive Compression – Based Congestion Control Technique
<i>ADPCM</i>	-	Adaptive Differential Pulse Code Modulation
<i>AODV</i>	-	Ad-hoc On Demand Distance Vector Routing
<i>AVG</i>	-	Average Queue
<i>BS</i>	-	Base Station
<i>CCA</i>	-	Clear Channel Assessment
<i>CCN</i>	-	Completely Connected Network
<i>CH</i>	-	Cluster Head
<i>CM</i>	-	Cluster Member
<i>CPF</i>	-	Consume Power Fairly protocol
<i>CS</i>	-	Compressive Sensing
<i>CSMA/CA</i>	-	Carrier – Sense Multiple Access with Collision Avoidance
<i>CWT</i>	-	Continuous Wavelet Transform
<i>DAIPas</i>	-	Dynamic Alternative Path Selection Scheme
<i>DD, DI</i>	-	Direct Diffusion
<i>DPCM</i>	-	Differential Pulse Code Modulation
<i>DSTD</i>	-	Distributed Structure Tree Depression Algorithm
<i>DWT</i>	-	Discrete Wavelet Transform
<i>EAP</i>	-	Energy Aware Protocol
<i>GPS</i>	-	Global Position System
<i>H</i>	-	Hop
<i>HAAR</i>	-	Alferid Haar Algorith
<i>HSV</i>	-	Hue, Saturation, Value
<i>HWT</i>	-	Haar Wavelet Transform
<i>IBSS</i>	-	Independent Basic Service Set
<i>IP</i>	-	Internet Protocol
<i>LEACH</i>	-	Low Energy Adaptive Clustering Hierarchy

<i>LVQ</i>	-	Learning Vector Quantization
<i>MAC</i>	-	Medium Access Control
<i>MANET</i>	-	Mobile Ad-Hoc Network
<i>MAX_{th}</i>	-	Maximum Threshold
<i>MSE</i>	-	Mean Square Error
<i>MSR</i>	-	Multi Scale Retinex
<i>N</i>	-	Node
<i>P</i>	-	Path
<i>PAN</i>	-	Personal Area Network
<i>PSNR</i>	-	Peak – Signal Noise Ratio
<i>RSS</i>	-	Received Signal Strength
<i>TARA</i>	-	a Topology Aware Resource Adaptation
<i>TMT</i>	-	Triangular Matrix Table
<i>WANET</i>	-	Wireless Ad-Hoc Network
<i>WSN</i>	-	Wireless Sensor Network



LIST OF SYMBOLS

d	-	distance
E	-	energy
f	-	link
H	-	hops
i,j	-	the link index from node i to node j
k	-	k-bit
T	-	hops
P	-	number of possible path
RP	-	residual power
TP	-	total power
PN	-	power needed
RT	-	routing table
E_R	-	energy receive
E_T	-	energy send
m	-	incremental cost
L	-	payload
b	-	fixed cost
U	-	used energy for each node
U_i	-	average used energy
N	-	total number of node in the network
n	-	number of bytes for data payload
σ	-	average of energy
pJ	-	<i>peak joule</i>
H	-	houre
J	-	joule

m	-	meter
m^2	-	<i>meter square</i>
sec	-	second
W_N	-	first level Haar wavelet
V_N	-	first level scaling signal
X	-	gray level of input image
$P(x)$	-	histogram of input image
L	-	total number of the gray level



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CHAPTER 1

INTRODUCTION

This chapter will discuss about the overview on wireless sensor network (WSN). The objectives according to the problem statement is also highlighted. The significant features of this research in the form of contribution are also provided.

1.1 Research background

Wireless sensor network (WSN) are a type of sensors spatially distributed to monitor physical or environmental conditions, such as pressure, temperature, sound, vibration, motion, pulse, machine health monitoring, environment, habitat monitoring, health care applications, home automation, and traffic control. WSNs have been used in versatile applications in many different fields such as civilian domains, building and industrial complexes. In industrial complexes it includes monitoring, process, and control. WSNs have no infrastructure except the sink node and few other controller nodes. It is categorized as infrastructure less network as compared to cellular network. Every node can communicate to an unknown number of nodes. Each sensor node manages a variety of network services such as data compression, coverage, localization, synchronization, and security. This breakdown of management is for the purpose of enhancing the network's overall performance. Typical WSN may consists of five-layer communication protocol stacks. They are physical layer, data link layer, network layer, transport layer, and application layer, in order. The most important concern in WSN is the need for low power operation because it is tiny and operates autonomously. These nodes collect data from their environment. They then cooperate to forward data to sink node. Due to their diversity, WSNs have massive probability for large number of applications with its own unique requirements and characteristics.

From this perspective, researchers develop different algorithms that are suitable for many different applications and scenarios. In WSN implementation, the specific issues that are taken into consideration by designers are data aggregation, data reliability, localization, node clustering, energy aware routing, events scheduling, fault detection and security.

Wireless sensor network had been widely used in the different fields such as military, health care monitoring, environmental and earth sensing, Industrial monitoring and control. WSN systems are perfect for an application in environmental evaluation wherein the specifications mandate a long-term distributed monitoring and control solutions to manage soil, water or climatic variations. Also, all sensor nodes must be able to decrease energy consumption and manage the resources efficiently.

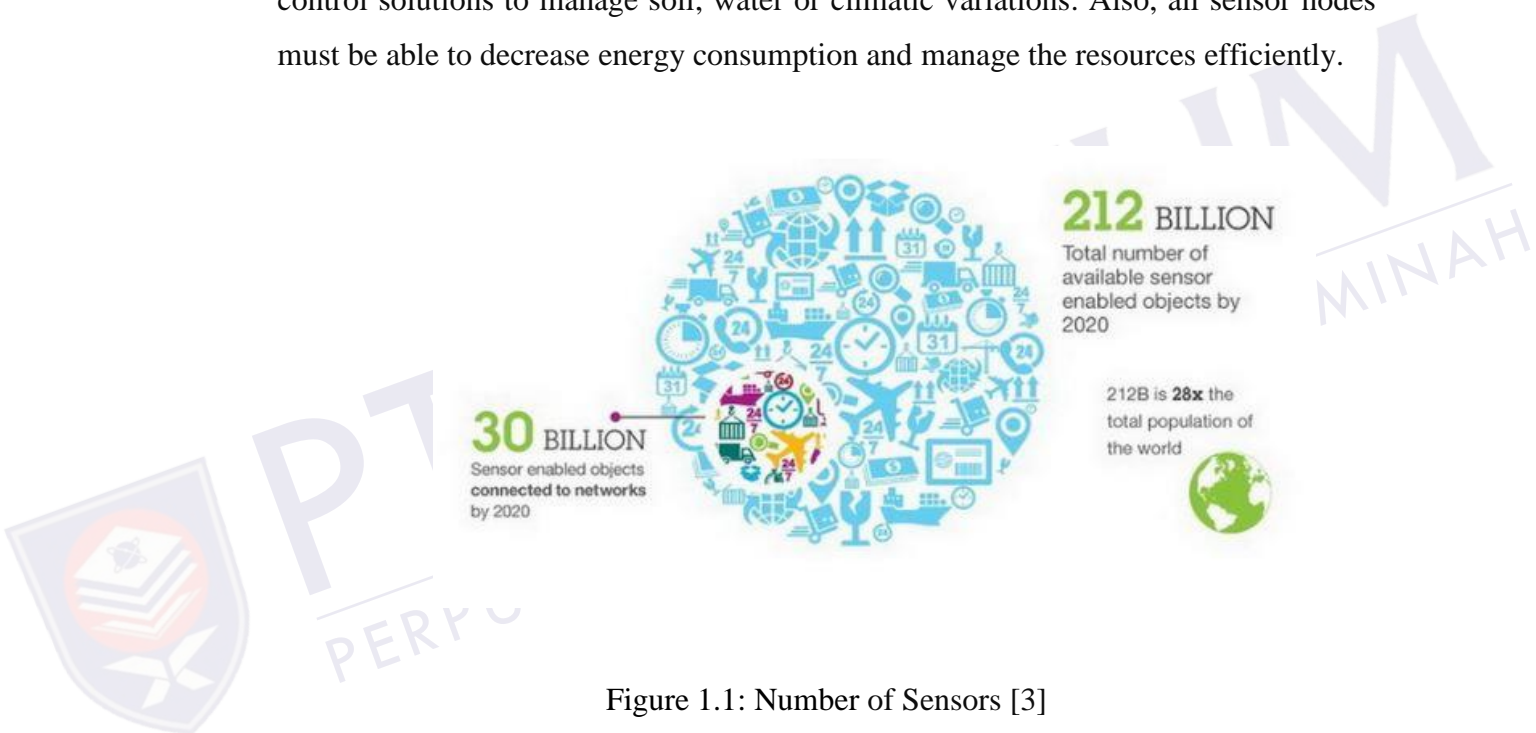


Figure 1.1: Number of Sensors [3]

In Figure 1.1 shows the huge number of sensors in the world. That's means in the future definitely the number will increase exponentially. Therefore, the world will face challenging issues in wireless communication techniques especially energy efficiency. The application of WSNs in industry brings huge benefits such as increasing remote sensing, without costing wires, besides this the benefits include energy and labour saving along with productivity increase. Additionally, the power cast technology can support many applications such as sensing temperature, humidity, management of industry, monitoring of industry and instrument health. The Figure 1.2 shows most application for WSN [3].



Figure 1.2: WSN Application [3]

WSN mostly use two famous protocols for network connectivity and transmissions namely ZigBee and IEEE 802.15.4. Both the protocols the max coverage range is between 50 – 100 m. Both the protocols were introduced to support low data rate applications. However, Both the technologies got merged later with the name of ZigBee. ZigBee is a low cost and low power connectivity solution with also power efficient solution for low power applications. Due to its diversity of applications this research also uses ZigBee protocol for data transmission and network connectivity between nodes.

WSN [1] is the subnet of wireless ad-hoc networks [2]. In WSN the most essential communication element is routing, since the backbone of a network is in charge of forwarding packets among nodes. The routing protocol layer plays an essential role in improving the performance of wireless networks for fixed and mobile nodes in the network. Forwarding of large amounts of data from one node to another may results in shorter network lifetime. In this case it may lead to possibility of death to the network. Therefore, it is desirable to design a routing protocol for WSN with the ability of achieving high power efficiency by distributing power consumption equally on all nodes in the network. This research ultimately considers a complete methodology for the energy consumption problem in sensor networks, and routing algorithm to support energy saving in the network. The traditional method is done by measuring selectively a low-power microcontroller or transceiver not sufficient to achieve energy saving over the entire network. Therefore, study and focus on the

design objectives looking into different aspects of application such as network configuration code, code, routing algorithms, data compression, and wireless devices to come up with an energy efficient network.

This research addresses the problem of unequal energy consumption in WSN that effects the network lifetime and throughput. A network routing protocol based on fair consumption of energy among the nodes have been introduced in order to prolong the network life time. It presents the simulated models for a 100 node network, distributed random in an area of 100 m^2 . A comparison has been drawn between the proposed and the energy aware protocol based on the number of dead nodes in the network after a designated number of iterations. In order to reduce the size of the transmitted data, data compression technique based on lossy compression has been implemented. In the end a combination of CPF protocol and data compression has been implemented and investigated thoroughly with different number of iterations to monitor the performance of a prolonged network connectivity.

1.2 Statement of problem

WSNs are usually deployed in rough physical environments with a limited battery power. The network may consist of hundreds or thousands of nodes with large physical distributions, making recharging almost impossible. Thus energy saving is always a key concern in such limited power systems. This problem has motivated the nodes, network and system designers to upgrade the traditional WSNs to reduce energy consumptions. In response, the IEEE 802.15.4 standard was introduced, however, it was developed to handle low data rate applications and needed longer durations for transmission to reduce power consumption.

Additionally in WSNs the communication of a far end node to the sink is made possible by intermediate nodes. Thus continuous routing of data packets from the node to sink via intermediate nodes exhausts the intermediate nodes and increases the power consumption at the intermediate nodes. Thus resulting in the death of intermediate nodes and creating of holes in the network. The intermediate nodes near the sink are the first ones to die due to highest power consumption. Thus, eventually with no load balancing, the WSN network collapses.

REFERENCES

1. K. Akkaya and M. Younis, "A survey on routing protocols for wireless sensor networks," *Ad Hoc Networks*, vol. 3, no. 3, pp. 325–349, May 2005.
2. C. Sergiou, V. Vassiliou, and A. Paphitis, "Congestion control in Wireless Sensor Networks through dynamic alternative path selection," *Comput. Networks*, vol. 75, pp. 226–238, Dec. 2014.
3. A. Bagula, "Applications of Wireless Sensor Network," no. February, pp. 1–67, 2012.
4. T. Rault, A. Bouabdallah, and Y. Challal, "Energy efficiency in wireless sensor networks: A top-down survey," *Comput. Networks*, vol. 67, pp. 104–122, Jul. 2014.
5. J. Kang, Y. Zhang, and B. Nath, "TARA: Topology-Aware Resource Adaptation to Alleviate Congestion in Sensor Networks," *IEEE Trans. Parallel Distrib. Syst.*, vol. 18, no. 7, pp. 919–931, Jul. 2007.
6. N. A. M. Alduais, A. Jamil, and J. Abdullah, "Performance Evaluation of Different Logical Topologies and Their Respective Protocols for Wireless Sensor Networks," *ARPJ. Eng. Appl. Sci.*, vol. 10, no. 19, pp. 8625–8634, 2015.
7. C. Bettstetter and Christian, "On the minimum node degree and connectivity of a wireless multihop network," in *Proceedings of the 3rd ACM international symposium on Mobile ad hoc networking & computing - MobiHoc '02*, 2002, p. 80.
8. IEEE Computer Society. LAN/MAN Standards Committee., Institute of Electrical and Electronics Engineers., and IEEE-SA Standards Board., *IEEE standard for information technology--telecommunications and information exchange between systems--local and metropolitan area networks--specific requirements. Part 11, Wireless LAN medium access control (MAC) and physical*

- layer (PHY) specifications. Amendment 10, Mesh networking. Institute of Electrical and Electronics Engineers, 2011.
9. D. Johnson, D. Johnson, N. Ntlatlapa, and C. Aichele, "A simple pragmatic approach to mesh routing using batman," *2ND IFIP Int. Symp. Wirel. Commun. Inf. Technol. Dev. COUNTRIES, PRETORIA, SOUTH AFRICA*, 2008.
 10. Ruitao Xie and Xiaohua Jia, "Transmission-Efficient Clustering Method for Wireless Sensor Networks Using Compressive Sensing," *IEEE Trans. Parallel Distrib. Syst.*, vol. 25, no. 3, pp. 806–815, Mar. 2014.
 11. F. Marcelloni and M. Vecchio, "A Simple Algorithm for Data Compression in Wireless Sensor Networks," *IEEE Commun. Lett.*, vol. 12, no. 6, pp. 411–413, Jun. 2008.
 12. G. J. Pottie and W. J. Kaiser, "Wireless integrated network sensors," *Commun. ACM*, vol. 43, no. 5, pp. 51–58, May 2000.
 13. N. Kimura and S. Latifi, "A survey on data compression in wireless sensor networks," in *International Conference on Information Technology: Coding and Computing (ITCC'05) - Volume II*, 2005, p. 8–13 Vol. 2.
 14. W. Song, "Strategies and Techniques for Data Compression in Wireless Sensor Networks," *TELKOMNIKA Indones. J. Electr. Eng.*, vol. 11, no. 11, Nov. 2013.
 15. D. Petrovic, R. C. Shah, K. Ramchandran, and J. Rabaey, "Data funneling: routing with aggregation and compression for wireless sensor networks," in *Proceedings of the First IEEE International Workshop on Sensor Network Protocols and Applications*, 2003., pp. 156–162.
 16. T. Arici, B. Gedik, Y. Altunbasak, and L. Liu, "PINCO: a pipelined in-network compression scheme for data collection in wireless sensor networks," in *Proceedings. 12th International Conference on Computer Communications and Networks (IEEE Cat. No.03EX712)*, pp. 539–544.
 17. F. Marcelloni and M. Vecchio, "Enabling energy-efficient and lossy-aware data compression in wireless sensor networks by multi-objective evolutionary optimization," *Inf. Sci. (Ny.)*, vol. 180, no. 10, pp. 1924–1941, May 2010.
 18. J.-H. Lee and I.-B. Jung, "Adaptive-Compression Based Congestion Control Technique for Wireless Sensor Networks," *Sensors*, vol. 10, no. 4, pp. 2919–2945, Mar. 2010.
 19. Song Lin, D. Gunopulos, V. Kalogeraki, and S. Lonardi, "A data compression technique for sensor networks with dynamic bandwidth allocation," in *12th*

International Symposium on Temporal Representation and Reasoning (TIME'05), 2005, pp. 186–188.

20. D. Slepian and J. Wolf, "Noiseless coding of correlated information sources," *IEEE Trans. Inf. Theory*, vol. 19, no. 4, pp. 471–480, Jul. 1973.
21. Y. Yaguang and Guigaung, "Study on Data Compression in Wireless Sensor Networks," *Comput. Appl. Softw.*, vol. 7, p. 2, 2010.
22. Si - Wang Zhou, "A Wavelet Data Compression Algorithm Using Ring Topology for Wireless Sensor Networks," *J. Softw.*, vol. 18, no. 3, pp. 669–674, 2007.
23. S. Lin, V. Kalogeraki, D. Gunopulos, and S. Lonardi, "Online Information Compression in Sensor Networks," in *2006 IEEE International Conference on Communications*, 2006, pp. 3371–3376.
24. J. Chou, D. Petrovic, and K. Ramchandran, "A distributed and adaptive signal processing approach to exploiting correlation in sensor networks," *Ad Hoc Networks*, vol. 2, no. 4, pp. 387–403, Oct. 2004.
25. S. S. Pradhan, J. Kusuma, and K. Ramchandran, "Distributed compression in a dense microsensor network," *IEEE Signal Process. Mag.*, vol. 19, no. 2, pp. 51–60, Mar. 2002.
26. W. R. Heinzelman, A. Chandrakasan, and H. Balakrishnan, "Energy-efficient communication protocol for wireless microsensor networks," in *Proceedings of the 33rd Annual Hawaii International Conference on System Sciences*, vol. vol.1, p. 10.
27. C. Intanagonwiwat, R. Govindan, D. Estrin, J. Heidemann, and F. Silva, "Directed diffusion for wireless sensor networking," *IEEE/ACM Trans. Netw.*, vol. 11, no. 1, pp. 2–16, Feb. 2003.
28. I. T. Almalkawi, M. Guerrero Zapata, and J. N. Al-Karaki, "A Secure Cluster-Based Multipath Routing Protocol for WMSNs," *Sensors*, vol. 11, no. 12, pp. 4401–4424, Apr. 2011.
29. L. A. Latiff, N. Fisal, S. A. Arifin, and A. Ali, "Directional Routing Protocol in Wireless Mobile Ad Hoc Network," in *Trends in Telecommunications Technologies*, InTech, 2010.
30. D. Slepian and J. Wolf, "Noiseless coding of correlated information sources," *IEEE Trans. Inf. Theory*, vol. 19, no. 4, pp. 471–480, Jul. 1973.
31. B. Karp and H. T. Kung, "GPSR," in *Proceedings of the 6th annual international conference on Mobile computing and networking - MobiCom '00*, 2000, pp.

243–254.

32. H. Zhang and H. Shen, “Energy-Efficient Beaconless Geographic Routing in Wireless Sensor Networks,” *IEEE Trans. Parallel Distrib. Syst.*, vol. 21, no. 6, pp. 881–896, Jun. 2010.
33. T. Rault, A. Bouabdallah, and Y. Challal, “Energy efficiency in wireless sensor networks: A top-down survey,” *Comput. Networks*, vol. 67, pp. 104–122, Jul. 2014.
34. M. M. Qabajeh, A. H. Abdalla, O. O. Khalifa, and L. K. Qabajeh, “A Survey on Scalable Multicasting in Mobile Ad Hoc Networks,” *Wirel. Pers. Commun.*, vol. 80, no. 1, pp. 369–393, Jan. 2015.
35. A. Boukerche, B. Turgut, N. Aydin, M. Z. Ahmad, L. Bölöni, and D. Turgut, “Routing protocols in ad hoc networks: A survey,” *Comput. Networks*, vol. 55, no. 13, pp. 3032–3080, Sep. 2011.
36. J. Gui and Z. Zeng, “Joint network lifetime and delay optimization for topology control in heterogeneous wireless multi-hop networks,” *Comput. Commun.*, vol. 59, pp. 24–36, Mar. 2015.
37. W. Dargie, R. Mochaourab, A. Schill, and L. Guan, “A topology control protocol based on eligibility and efficiency metrics,” *J. Syst. Softw.*, vol. 84, no. 1, pp. 2–11, Jan. 2011.
38. H.-Y. Kung, C.-M. Huang, H.-H. Ku, and Y.-J. Tung, “Load Sharing Topology Control Protocol for Harsh Environments in Wireless Sensor Networks,” in *22nd International Conference on Advanced Information Networking and Applications (aina 2008)*, 2008, pp. 525–530.
39. Li Jun, “A cross-layer routing optimization method in Wireless Mesh Network,” in *2013 IEEE 4th International Conference on Software Engineering and Service Science*, 2013, pp. 357–360.
40. G. Karbaschi and A. Fladenmuller, “A link-quality and congestion-aware cross layer metric for multi-hop wireless routing,” in *IEEE International Conference on Mobile Adhoc and Sensor Systems Conference, 2005.*, pp. 649–655.
41. A. Vázquez-Rodas and L. J. de la Cruz Llopis, “A centrality-based topology control protocol for wireless mesh networks,” *Ad Hoc Networks*, vol. 24, pp. 34–54, Jan. 2015.
42. K. Jaffrès-Runser, M. R. Schurgot, Q. Wang, C. Comaniciu, and J.-M. Gorce, “A cross-layer framework for multiobjective performance evaluation of wireless ad

- hoc networks,” *Ad Hoc Networks*, vol. 11, no. 8, pp. 2147–2171, Nov. 2013.
43. M. Haghpanahi, M. Kalantari, and M. Shayman, “Topology control in large-scale wireless sensor networks: Between information source and sink,” *Ad Hoc Networks*, vol. 11, no. 3, pp. 975–990, May 2013.
 44. A. Ghaffari, “Congestion control mechanisms in wireless sensor networks: A survey,” *J. Netw. Comput. Appl.*, vol. 52, pp. 101–115, Jun. 2015.
 45. S. Mahdizadeh Aghdam, M. Khansari, H. R. Rabiee, and M. Salehi, “WCCP: A congestion control protocol for wireless multimedia communication in sensor networks,” *Ad Hoc Networks*, vol. 13, pp. 516–534, Feb. 2014.
 46. İ. Bekmezci, O. K. Sahingoz, and Ş. Temel, “Flying Ad-Hoc Networks (FANETs): A survey,” *Ad Hoc Networks*, vol. 11, no. 3, pp. 1254–1270, May 2013.
 47. D. G. Reina, S. L. Toral, P. Johnson, and F. Barrero, “A survey on probabilistic broadcast schemes for wireless ad hoc networks,” *Ad Hoc Networks*, vol. 25, pp. 263–292, Feb. 2015.
 48. J. N. Al-Karaki and A. E. Kamal, “Routing techniques in wireless sensor networks: a survey,” *IEEE Wirel. Commun.*, vol. 11, no. 6, pp. 6–28, Dec. 2004.
 49. T. K. Jain, D. S. Saini, and S. V. Bhooshan, “Lifetime Optimization of a Multiple Sink Wireless Sensor Network through Energy Balancing,” *J. Sensors*, vol. 2015, pp. 1–6, Apr. 2015.
 50. L. Popa, A. Rostamizadeh, R. Karp, C. Papadimitriou, and I. Stoica, “Balancing traffic load in wireless networks with curveball routing,” in *Proceedings of the 8th ACM international symposium on Mobile ad hoc networking and computing - MobiHoc '07*, 2007, p. 170.
 51. J. Li and P. Mohapatra, “Analytical modeling and mitigation techniques for the energy hole problem in sensor networks,” *Pervasive Mob. Comput.*, vol. 3, no. 3, pp. 233–254, Jun. 2007.
 52. B. Krishnamachari, *Networking wireless sensors*. Cambridge University Press, 2005.
 53. D. Ye, M. Zhang, and Y. Yang, “A multi-agent framework for packet routing in wireless sensor networks,” *Sensors (Basel)*, vol. 15, no. 5, pp. 10026–47, Apr. 2015.
 54. B. Cheng, R. Du, B. Yang, W. Yu, C. Chen, and X. Guan, “An Accurate GPS-Based Localization in Wireless Sensor Networks: A GM-WLS Method,” in *2011*

- 40th International Conference on Parallel Processing Workshops*, 2011, pp. 33–41.
55. S. Capkun, M. Hamdi, and J.-P. Hubaux, “GPS-free positioning in mobile ad-hoc networks,” in *Proceedings of the 34th Annual Hawaii International Conference on System Sciences*, p. 10.
 56. H. Akcan, V. Kriakov, H. Brönnimann, and A. Delis, “GPS-Free node localization in mobile wireless sensor networks,” in *Proceedings of the 5th ACM international workshop on Data engineering for wireless and mobile access - MobiDE '06*, 2006, p. 35.
 57. D. Kumar, T. C. Aseri, and R. B. Patel, “EECDA: Energy Efficient Clustering and Data Aggregation Protocol for Heterogeneous Wireless Sensor Networks,” *Int. J. Comput. Commun. Control*, vol. 6, no. 1, p. 113, Mar. 2011.
 58. J. Xu, N. Jin, X. Lou, T. Peng, Q. Zhou, and Y. Chen, “Improvement of LEACH protocol for WSN,” in *2012 9th International Conference on Fuzzy Systems and Knowledge Discovery*, 2012, pp. 2174–2177.
 59. C. Fu, Z. Jiang, W. Wei, and A. Wei, “An Energy Balanced Algorithm of LEACH Protocol in WSN,” *Int. J. Comput. Sci. Issues*, vol. 10, no. 1, pp. 354–359, 2013.
 60. L. Alazzawi and A. Elkateeb, “Performance Evaluation of the WSN Routing Protocols Scalability,” *J. Comput. Syst. Networks, Commun.*, vol. 2008, pp. 1–9, Mar. 2008.
 61. A. A. R. T. Rahem, M. Ismail, and A. Saad, “A triangular matrix routing table representation for efficient routing in MANET,” *J. Theor. Appl. Inf. Technol.*, vol. 64, no. 2, pp. 401–412, 2014.
 62. L. M. Feeney and M. Nilsson, “Investigating the energy consumption of a wireless network interface in an ad hoc networking environment,” in *Proceedings IEEE INFOCOM 2001. Conference on Computer Communications. Twentieth Annual Joint Conference of the IEEE Computer and Communications Society (Cat. No.01CH37213)*, 2001, vol. 3, pp. 1548–1557.
 63. Y. Donoso and R. Fabregat, *Multi-objective optimization in computer networks using metaheuristics*. Auerbach Publications, 2007.
 64. R. Bhardwaj, Anuj; Ali, “Image compression using modified fast HAAR wavelet transform,” *World Appl. Sci. J.*, vol. 7, no. 5, pp. 647–653, 2009.
 65. Y. Bengio, “Learning Deep Architectures for AI,” *Found. Trends® Mach.*

- Learn.*, vol. 2, no. 1, pp. 1–127, Nov. 2009.
66. W. Dargie and C. Poellabauer, *Fundamentals of Wireless Sensor Networks*. Chichester, UK: John Wiley & Sons, Ltd, 2010.
 67. G. E. Hinton and R. R. Salakhutdinov, “Reducing the dimensionality of data with neural networks,” *Science*, vol. 313, no. 5786, pp. 504–7, Jul. 2006.
 68. M. Hanmandlu, O. P. Verma, N. K. Kumar, and M. Kulkarni, “A Novel Optimal Fuzzy System for Color Image Enhancement Using Bacterial Foraging,” *IEEE Trans. Instrum. Meas.*, vol. 58, no. 8, pp. 2867–2879, Aug. 2009.
 69. E. H. Land, “The retinex theory of color vision,” *Sci. Am.*, 1977.
 70. E. H. Land and J. J. McCann, “Lightness and retinex theory,” *J. Opt. Soc. Am.*, vol. 61, no. 1, pp. 1–11, Jan. 1971.
 71. Z. Rahman and Z. Rahman, “Properties Of A Center/Surround Retinex - Part One: Signal Processing Design,” 1995.
 72. A. K. Vishwakarma and A. Mishra, “Color Image Enhancement Techniques: A Critical Review,” *Indian J. Comput. Sci. ...*, vol. 3, no. 1, pp. 39–45, 2012.
 73. C. Zhe, C. Li, and J. Meng, “The Traffic Image is Dehazed Based on the Multi-Scale-Retinex Algorithm and Implement it in FPGA,” in *Proceedings of the 3rd International Conference on Mechatronics and Industrial Informatics*, 2015.
 74. H. Talukder, Kamrul Hasan; Koichi, “HAAR wavelet based approach for image compression and quality assesment of compressed image,” *Int. J. Appl. Math.*, vol. 36, no. 1, pp. 1–9, 2007.
 75. R. N. Enam, M. Imam, and R. I. Qureshi, “Energy Consumption in Random Cluster Head selection Phase of,” vol. 30, no. May, pp. 38–44, 2012.
 76. L. M. Feeney and M. Nilsson, “Investigating the energy consumption of a wireless network interface in an ad hoc networking environment,” in *Proceedings IEEE INFOCOM 2001. Conference on Computer Communications. Twentieth Annual Joint Conference of the IEEE Computer and Communications Society (Cat. No.01CH37213)*, 2001, vol. 3, pp. 1548–1557.
 77. N. A. M. Alduais, L. Audah, A. Jamil, and J. Abdullah, “Study the effect of number of nodes in large-scale Wireless Sensor Networks with design GUI support tools,” *ARN J. Eng. Appl. Sci.*, vol. 11, no. 22, pp. 13259–13264, 2016.
 78. “SIPI Image Database.” [Online:<http://sipi.usc.edu/database/database.php>.] [Accessed: 03-Jul-2018].